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BIOLOGICAL CONTROL OF INSECT PESTS: SOUTHEAST ASIAN PROSPECTS

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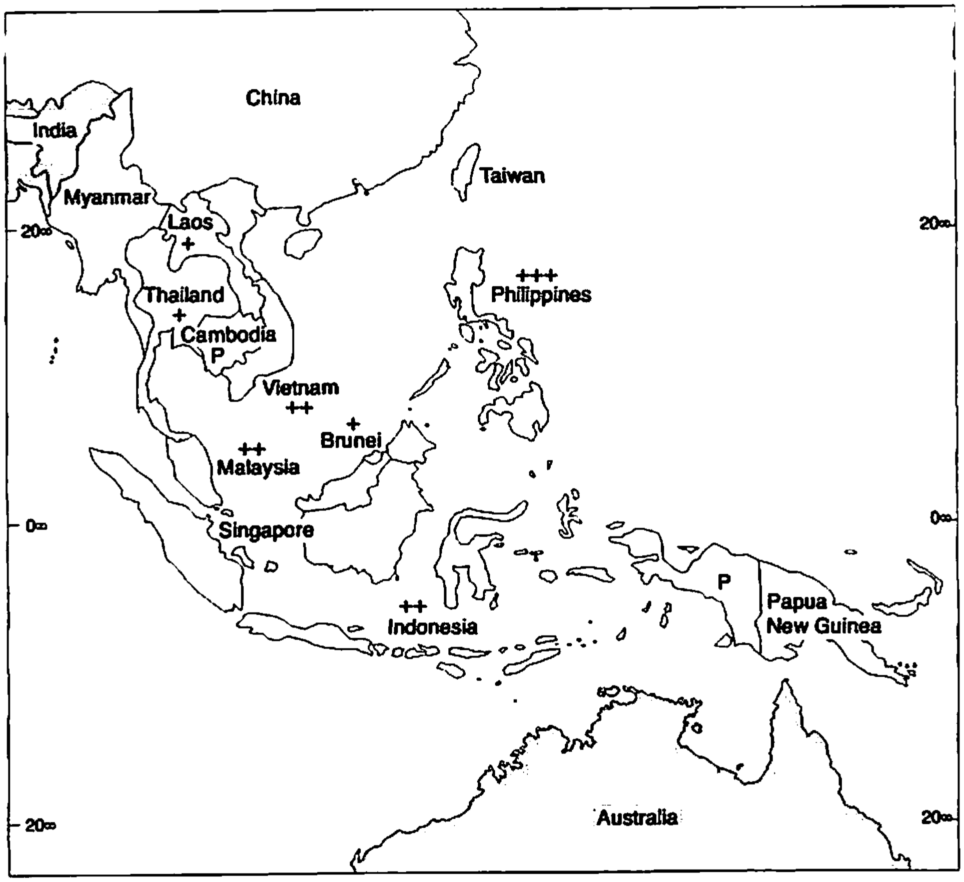
4.10 *Hypothenemus hampei*



Hypothenemus hampei is native to Central Africa but has spread to most coffee producing countries in Central and South America, to Southeast Asia and to several Pacific countries. Significant coffee-growing areas not yet infested are Hawaii, Papua New Guinea, Vanuatu and Solomon Islands.

It is a pest exclusively of coffee berries and does not damage the vegetative parts. It is difficult to control with chemicals and, although plantation management methods can reduce damage, the coffee berry borer remains an important pest.

The most important natural enemies appear to be 3 parasitic wasps native to Africa, *Cephalonomia stephanoderis*, *Phymastichus coffea* and *Prorops nasuta*. The last of these has been established in Brazil and Colombia without its own natural enemies, but has not so far produced spectacular results. *C. stephanoderis* has been established recently in Colombia, Ecuador, Mexico and New Caledonia, but it is too early to evaluate its impact. *Phymastichus coffea* has not yet been established anywhere, but this is foreshadowed in Colombia. The fungus *Beauveria bassiana* shows early promise. A thorough study is in progress of the interactions of the parasites and other natural enemies of *H. hampei* and the influence on them of various components of the environment. Optimism has been expressed about the outcome of this program.

Hypothenemus hampei (Ferrari)

Coleoptera: Scolytidae

coffee berry borer

Rating

Southeast Asia			Southern and Western Pacific		
	+++	Phil		+++	N Cal
12	++	Viet, Msia, Indo	7	++	Fiji, Fr P
	+	Thai, Laos, Brun			
	P	Camb		P	Pohnpei, Saipan

This account updates the chapter on *H. hampei* in Waterhouse and Norris (1989) and the valuable review of Murphy and Moore (1990) in relation to prospects for biological control.

Origin

Ferrari's specimens, described in 1867 under the generic name *Stephanoderes*, were obtained from trade coffee beans in France. There appears to be no record of the country of origin of the material, but in 1867 infested beans could only have come from Africa or Saudi Arabia, because *Hypothenemus hampei* did not obtain a footing on other continents until later. The seed used to establish *Coffea arabica* in Saudi Arabia was probably obtained from the Ethiopian highlands centuries ago. There the coffee berry borer is native, though scarce (Davidson 1967), but if it did not accompany the original seed it could easily have reached Saudi Arabia through Arabian-African commerce over the centuries.

The wider range of parasitoids (3) in West Africa than in East Africa (2, with one shared with the West) suggests that *H. hampei* has been in the West for a very long time and may indeed have evolved there (L.O. Brun pers. comm.).

Distribution

This was given by CIE (1981) as: **Africa** (Angola, Benin, Burundi, Cameroon, Canary Is, Central African Republic, Chad, Congo, Ethiopia, Fernando Poo, Gabon, Ghana, Guinea, Ivory Coast, Kenya, Liberia, Malawi, Mozambique, Nigeria, Principe, Rio Muni, Rwanda, São Tomé, Senegal, Sierra Leone, Sudan, Tanzania, Togo, Uganda and Zimbabwe); **Middle East** (Saudi Arabia), **Asia** (Indonesia, Cambodia, Laos, Malaysia, Philippines, Sri Lanka, Thailand, Vietnam); **Central America** (Guatemala, Honduras, Greater West Indies); **South America** (Brazil, Peru, Surinam); **Pacific** (Caroline Is, Irian Jaya, Marianas Is, New Caledonia, Society Is).

To these must be added: **South America** (Colombia in 1988 (D. Moore pers. comm. 1989), Ecuador (CIBC 1988a, b)); **Central America** (El Salvador, Mexico (Baker 1984)); **Asia** (India (Kumar et al. 1990)) and the **Pacific** (Fiji (Anon. 1979a), Tahiti (Johnston 1963)). In the **West Indies**, Reid (1983) reported the beetle from Jamaica and Puerto Rico, but it has not been reported from the lesser West Indies (Guadeloupe).

Significant coffee-growing or potential coffee-growing areas not yet infested are Solomon Is, Vanuatu, Hawaii and Papua New Guinea, although the latter is at serious risk because it shares a common land frontier with Irian Jaya (Indonesia), where *H. hampei* has been present for many years (Thomas 1961). *H. hampei* is not present in Australia.

Biology

The following description of the life cycle refers exclusively to the relationship of the beetle with *Coffea* spp., and principally with Arabian coffee *C. arabica* and robusta coffee *C. canephora*, the most important cultivated species. Infestations of *H. hampei* occur in coffee seeds while they are enclosed in berries on the trees and in berries that fall to the ground. They will also continue vigorously in processed beans in storage, but not if the moisture content has been reduced below 12.5% (robusta beans) or 13.5% (arabica beans) (Hargreaves 1935). Apart from dispersive flight by adult females and the walking by males from one berry to another on the same branch (P. Cochereau pers. comm. 1995), no part of the life cycle of the coffee berry borer is passed through outside of the coffee bean.

The length of adult females of *H. hampei* of American origin is given as 1.4 to 1.7 mm (Wood 1982) and of Ugandan females and males as about 1.9 mm and 1.3 mm respectively (Hargreaves 1926). Malaysian females averaged 1.58 mm and males 0.99 mm (Corbett 1933). Females outnumber males by at least 10 to 1 and the ratio is frequently much higher. The beetle is brown when it first emerges from the pupa but in the course of 4 or 5 days it becomes generally black, although the prothorax has a slightly reddish tinge. The prothorax is markedly humped, so that the down-turned head is not visible from above. The tibiae have strong spines which doubtless assist in such activities as tunneling through the pulp of coffee berries, ejecting the resulting frass, and forcing a way to the soil surface should the berry become interred.

Beetle attack tends to be aggregated on some trees or on particular branches within trees, rather than evenly distributed (Baker 1984). The fertilised female flies to coffee berries that have begun to ripen and bores an entrance hole at the apex, either in the terminal pore or in the calyx ridge or annulus of differentiated tissue that surrounds the pore. Sometimes this annulus is perforated by several holes, but boring into the fruit elsewhere is unusual. The colour of berries appears not to influence choice by females seeking oviposition sites (Morallo-Rejesus and Baldos 1980). Young berries, containing seeds with a watery endosperm, usually do not come under attack if more advanced berries are plentiful. If they do they are soon abandoned, after the female has fed on some of the pulp, and they then tend to fall prematurely, being particularly vulnerable to infection by disease organisms. The falling of such immature berries after being attacked often contributes significantly to the amount of crop lost. After the endosperm has passed from the watery to the milky stage in the course of maturation, beetles invading the berry will wait in the pulp until the seed tissue is firm enough to excavate (Penatos and Ochoa 1979). Rhodes and Mansingh (1981) cite opinions to the effect that females that become static in this fashion for several weeks (May to mid-July in the Jamaican lowlands) are in a state of reproductive diapause. When available, berries are selected that are already suitable for colonisation. The green berry is favoured for feeding and the ripe (i.e. red) berry for breeding purposes, but the ripe berries are also very suitable for feeding (Corbett 1933). In a ripe berry the female bores in one operation through skin, pulp and the endocarp and pellicle surrounding one of the two seeds (beans) present in each berry. Ejected frass may surround the entrance hole during boring (Hutson 1936). Several days may be occupied in this boring process, and the female then tunnels into the endosperm, the substance of the seed, which is the basis of the world's US$8 billion annual coffee crop (Bardner 1978). Berries that fall to the ground may generate considerable numbers of beetles, but these are from their on-tree infestation, since the female berry borers do not appear to visit fallen fruit (Baker 1984).

The eggs are laid at the rate of two or three a day in batches of 8 to 12 in chambers chewed out of the maturing bean tissue. Oviposition extends over a period of three to seven weeks, each female producing from about 30 to over 70 eggs. According to some authors, laying is not necessarily confined to one bean because the female that has initiated an infestation may fly to other berries during the oviposition period. According to others (e.g. Bergamin 1943) the female that has initiated an infestation only quits the bean when the first of her progeny emerge as adults. Others again (e.g. Hargreaves 1935) state that she remains until all the bean tissue is consumed or has deteriorated in some way. Most likely the pattern is quite flexible. Eggs hatch in three to nine days and young larvae bore into intact bean

contradicts ♀ staying in berry

contradicts statement that ♀ doesn't leave brood tissue, making pockets opening off the main tunnel made by the parent female. Male larvae pass through their two instars in the course of about 15 days, and the females pass through three instars in about 19 days (Bergamin 1943). Morallo-Rejesus and Baldos (1980) state that the female, like the male, passes through only two instars, indicating the need for further biological study. The long period over which oviposition is spread results in larvae in all stages of development being present in one bean. At the end of the larval stage there is a non-feeding or prepupal stage lasting about two days. The insect then pupates, without any cocoon formation, in the galleries excavated by the larvae. The pupal stage is passed through in four to nine days. The period from egg-laying to the emergence of the adult is 25 to 35 days. The temperatures at which the preceding records were made are generally not specified, but chiefly they relate to warm lowland coffee plantations. Bergamin (1943) recorded that at 24.5°C in Brazil the period from egg-laying to emergence of adult averaged 27.5 days. De Oliveira Filho (1927) found that in Brazil shade temperatures of 20 to 30°C suited the females best. Below 15°C they became inactive, endeavouring to hide, preferably in coffee berries, but sometimes by boring into beans, maize, peanuts or cotton seed of suitably low moisture content. They can survive temperatures just below 0°C, which however are rarely experienced in Brazilian coffee growing areas. At higher elevations development is somewhat prolonged (Le Pelley 1968) and *H. hampei* has a low pest status in highland coffee growing areas in East Africa and Java (Haarer 1962). Baker et al. (1989) conclude that the optimum mean annual temperature for the beetle is 23° to 25°C and that parasitoids for biological control should be sought from a similar climate.

instar

The adult males emerge from the pupa earlier than the females. Their hindwings are short and they do not fly, but remain in the bean, fertilising their female siblings as they emerge. Each male can fertilise two females a day and up to 30 in his lifetime which may extend to 103 days, although averaging less. Corbett (1933) states that the males seldom leave the berries, and then only when they are near death. The vast majority of observers confirm that males never leave the berries. Quite likely they may move from bean to bean within a fruit, thereby gaining access to females other than their sisters. Parthenogenesis does not occur and, although unfertilised females may produce some eggs, these do not hatch. One insemination is sufficient to allow a female to lay fertile eggs throughout her reproductive period. Corbett (1933) stated that, if there are no males in the seed when the females emerge from the pupal skin after their hardening period of a few days, they leave via the entrance hole and seek males in other infested berries. Morallo-Rejesus and Baldos (1980) suggest that sex pheromones secreted by the males guide such females to appropriate berries.

♂ sex pheromones

Females that have been fertilised remain in the 'parental' bean for three or four days, by which time they have become sexually mature. They then leave the berries via the entrance holes and enter others and, after a preoviposition period of 4 to 20 days, commence egg laying. Females have been known to live up to 282 days, and longevity was stated by Bergamin (1943) to average 156 days. According to Corbett (1933), in Malaysia females survived 81 days without food. There is time for a succession of seven or eight generations a year in lowland coffee growing areas but, on account of the long reproductive period, there are few clearcut population peaks to indicate generations.

AGE (longevity) of ♀'s

Table 14 (p.64) in Bergamin (1943)

Life history studies have been carried out with artificial infestations of coffee trees in southern Mexico (Baker et al. 1992). Morallo-Rejesus and Baldos (1980) observed in the Philippines that beetles are to be observed in flight from 3.00 pm, considerable numbers being visible in the air between 4.00 and 5.00 pm. Corbett (1933) observed in Malaysia that females fly at any time during the day, but in greatest numbers between 2.00 and 5.00 pm, reaching a peak between 3.30 and 4.30 pm. De Oliveira Filho (1927) states that, in Brazil, females 'are active' on warm nights, but it is unclear whether this implies flight activity. Kalshoven (1981) states that, in Java, females start flying during the midday period, and that they assemble under leaves and in other places where they dance up and down like gnats. Such activity can have no sexual significance, seeing that the males do not leave the seeds, and its function is obscure. In Java flights up to 345 m have been measured (Leefmans 1920). In Mexico, Baker (1984) carried out experimental studies on flight. Females flew freely in the laboratory for up to 22 minutes, tending to hover or move forward only slowly. In tethered flight, and thus relieved of supporting their own weight, they could fly non-stop for 100 minutes, with a combined aggregate of three hours. Such enduring activity, combined with its afternoon peak of activity, suggests that, in their habits, the beetles resemble aphids and thrips in being adapted to exploiting periods of maximum convection in the atmosphere, so achieving long-distance travel with their own contribution serving chiefly to keep them aloft. De Oliveira Filho (1927) states that local flight occurs when the fertilised female is seeking a place to lay, when (oviposition having commenced) she emerges to seek moister berries after having been driven out by the heat of the sun. It also occurs when unfertilised females seek males (as they do if there are none in the berry when they emerge), when seeds are waterlogged, are overcrowded with adults and larvae, or when the beetles are disturbed.

flight

Rhodes and Mansingh (1981) state that, in the Jamaican lowlands, beetles in dry berries remain in diapause for five months, from mid-December to mid-May. Baker (1984) found that in mid-spring in Mexico females tended to remain in fallen coffee berries at a time when temperatures in berries in the trees ranged up to an inimical 37°C. Soaking the fallen berries in water induced many to emerge, but they did so in a specific pattern, some seven to eight hours after dawn. Possibly the soaking simulated rain that would have made the environment generally more favourable. Baker reminds us that coffee is naturally an understorey plant in tropical forest and, by sheltering in fallen berries, beetles may avoid the harmful effects of strong, direct sunlight. Infestations are carried over between peaks of fruiting by the breeding that occurs in late-maturing berries, or else in those that have fallen to the ground. Females can survive for up to two months in buried beans (Clausen 1978).

It is probable that intercontinental travel is brought about by the agency of man, rather than by travel in moving air masses. Infested beans are an obvious vehicle for dispersal, but there are other avenues to which quarantine measures should be applied. In Jamaica, Reid (1983) observed females among banana trash used in packing boxes on their way to the boxing plant. Commonly, beetles disperse in sacks, empty or otherwise, and on the clothing and equipment of plantation workers. Under some conditions beetles bore for protection into wood or other materials to the extent that Baker (1984) suggested that authorities in beetle-free areas should think very carefully before allowing entry of untreated plant material from an infested area.

Host plants

An important aspect of the biology of any insect pest is its host range. In Africa, in addition to its regular hosts in the genus *Coffea*, *Hypothenemus hampei* has been reported from fruit, pods or seeds of species of *Centrosema*, *Crotalaria*, *Phaseolus* and *Tephrosia* (Fabaceae), *Leucaena* (Mimosaceae), *Caesalpinia* (Caesalpiniaceae), *Hibiscus* (Malvaceae), *Rubus* and *Oxyanthus* (Rubiaceae), *Vitis* (Vitaceae) and *Ligustrum* (Oleaceae), but these associations are all considered to reflect only casual feeding by adults. In Africa, the only species outside of the genus *Coffea* in which immature stages have been found is *Dialium lacourtianum* (Caesalpiniaceae) (Le Pelley 1968).

A review of hosts of the genus *Hypothenemus* was made by Johanneson and Mansingh (1984) who concluded that *H. hampei* was monophagous according to their criteria, as it attacked only six species of the genus *Coffea*. However, they listed 23 other species of plants in 11 families from which *H. hampei* has been recorded, but only as adult females. In contrast, in the Philippines, Morallo-Rejesus and Baldos (1980), whose paper was overlooked by Johanneson and Mansingh, reported finding eggs, larvae and pupae of *H. hampei* in *Leucaena leucocephala* (Mimosaceae), *Gliricidia sepium* (Fabaceae), two species of *Psychotria* (Rubiaceae) and one of *Dioscorea* (Dioscoreaceae). In laboratory tests they found that adults of *H. hampei* fed on pods of four of those species and also on the pods of 19 other species in 9 orders.

Such feeding tests may be of little significance, however, since the survival times recorded are greatly exceeded by the periods for which the beetles are capable of withstanding starvation (Corbett 1933). If the insects were correctly identified, the host plants recorded in the Philippines may help to support a population of *H. hampei* when no coffee berries are available. Reexamination of the host range is necessary. For example Cohic (1958) found *H. hampei* attacking loquat in New Caledonia, and this relationship, though abortive in the end, has not been reported anywhere else in the world. In connection with host records, Johanneson and Mansingh (1984) drew attention to the problem of misidentification of species of *Hypothenemus*, a notoriously difficult genus, and also to misinterpretation of the relative roles of various host plants. Hargreaves (1935) found adults of four species of *Hypothenemus* other than *H. hampei* in seed of *Phaseolus lunatus* (Fabaceae) in Uganda, and Gonzalez (1978) alludes to species of *Hypothenemus*, known as false coffee borers, which occur from Mexico to northern Argentina and greatly complicate quarantine procedures. Such insects would, of course, also raise difficulties in host plant studies. A thorough review of true hosts of *H. hampei* would be relevant to a number of aspects of the control of this pest.

Damage

Hypothenemus hampei is a pest exclusively of the immature and mature coffee berries and does no damage whatsoever to the vegetative parts of the plant. Prates (1969) showed that adults of *H. hampei* were strongly attracted to extracts of green or ripe coffee berries, but not to extracts of coffee leaves or flowers. Significant losses are caused by the female beetles feeding on young berries which are too immature to colonise but which, after the beetle has gone, are invaded by decay organisms, and so fall prematurely. In Java Leefmans (1920) found that 80% of green berries that had fallen through being bored by the beetle contained decayed beans as against 46.5% in unbored beans that had fallen through other causes. In the Congo, Schmitz and Crisinel (1957) found that 64 to 82% of shed berries had fallen on account of *H. hampei* attack. Such losses caused by attack on immature fruits are serious enough, but the bulk of the damage done by this beetle is to the endosperm of the mature beans, which may be extensively damaged or even completely destroyed. Even lightly bored beans acquire a distinctive blue-green staining which significantly reduces their market value (McNutt 1975), but the further tunnelling by the beetles and their larvae brings about progressive degradation, so that the coffee bean is reduced to a mass of frass. Market requirements demand the removal of damaged berries from the harvested crop, which is done by various mechanical processes (fortunately bored beans float), supplemented even by handpicking. The beans removed by such processing are not necessarily a total loss, but can go into only low grade fractions at a much reduced market rate.

In New Caledonia, where no control measures had been implemented, *H. hampei* was found to have attacked 80% of berries (Cohic 1958). Other examples of losses due to *Hypothenemus hampei* are given by Le Pelley (1968). Severe infestations in Uganda may result in 80% of berries being attacked. In the Ivory Coast, damage of 5% to 20% of berries is common, rising to 50% to 80% in some cases. In the Congo, boring of up to 84% of green berries and up to 96% of hard berries has been recorded and, in Tanzania, records indicate up to 96% boring of hard berries. In Malaysia there have been records of up to 90% of beans damaged. In Java crop loss of 40% was recorded in 1929, and in Brazil 60% to 80% losses have been experienced. The above figures apply for the most part to poorly managed situations, and crop losses can be reduced by appropriate management, but the beetle is a constant latent threat if vigilance is relaxed. In Jamaica, Reid (1983) estimated that 27% of the berries harvested were damaged. The studies of Reid and Mansingh (1985) showed that *H. hampei* was responsible for 20.9% reduction of exportable beans in the Jamaican crop of 1980–81. Baker (1984) reported that, in southern Mexico, the attack of *H. hampei* on coffee plantations was so severe that, in spite of application of insecticides in some places in 1982, no berries were harvested because it would not have been economical to do so.

Proper processing results in beans of moisture content too low to permit the borer to multiply. This is below 13.5% for arabica coffee and below 12.5% for robusta coffee. If coffee beans are stored with significantly higher moisture content, beetle reproduction continues. Thus Morallo-Rejesus and Baldos (1980) found that, in the Philippines, infestation in coffee beans stored before drying rose from 20% to 100% in six weeks.

Natural enemies

The cryptic nature of the immature stages and the male of *H. hampei* makes them relatively inaccessible victims for predators, and the only one recorded is the non-specific Javanese bug *Dindymus rubiginosus*. This bug draws the borers from the berries with its beak and sucks them dry. Le Pelley (1968) states that it is of little importance.

The most important parasitic wasps, *Cephalonomia stephanoderis*, *Prorops nasuta*, *Phymastichus coffea* and *Heterospilus coffeicola* are, of course, African in origin and are dealt with in some detail by Klein Koch et al. (1988) and Feldhege (1992). *C. stephanoderis* which is restricted to West Africa is the most important species in Ivory Coast, parasitising up to 50% of *H. hampei* in black berries (Ticheler 1961). The potential of *H. coffeicola* in biological control requires further study because its larvae are not very specific, but the other three species appear to have a narrow enough host range to make them acceptable from this point of view. A fifth parasite, *Goniozus* sp. is recorded, but without further data, from Ivory Coast (Cochereau and Potiaroa 1994).

In addition to the identified arthropod natural enemies (Table 4.10.1), Leefmans (1924a) recorded a non-specific parasite that attacks beetles in newly infested berries and Hargreaves (1926) found an unidentified hymenopterous parasitoid in Uganda, now known also from Togo as *Aphanogmus dictynna* and considered to be a hyperparasitoid of *C. stephanoderis* or *P. nasuta* (Feldhege 1992). Morallo-Rejesus and Baldos (1980) reported the presence in the Philippines of a braconid and an encyrtid parasitoid of *H. hampei*, both unidentified, and presumably non-specific members of the local fauna.

Some ants attack the borer. Swallows and other small birds that feed on the wing consume flying adults of *H. hampei*.

The parasitic fungus *Beauveria bassiana* has been observed attacking *H. hampei* in Brazil (Averna-Saccá 1930; Villacorta 1984), Jamaica (Rhodes and Mansingh 1981), Cameroon (Pascalet 1939), Congo (Sladden 1934; Steyaert 1935), Ivory Coast (Ticheler 1961), India (Balakrishnan et al. 1994), Java (Friederichs and Bally 1922) and in New Caledonia (Cochereau and Potiaroa 1994). Steyaert (1935) and Averna-Saccá (1930) studied the seasonal cycle and the former also made studies of the infectivity and epidemiology of the fungus of which there are many strains. In an analysis of 16 isolates from *H. hampei* adults from 10 countries in Latin America, Africa, Asia and the Pacific, 13 formed a homogenous group with very similar electrophoretic and physiological characteristics, suggesting a distinct strain associated widely with the coffee berry borer. Of the remaining 3 strains, one from Sri Lanka is suspected as having degenerated during some 63 years in storage, but the others (from New Caledonia and Kenya) are probably distinct entities (Bridge et al. 1990). The New Caledonian strain presumably attacked some other host until *H. hampei* arrived there in 1948. It is a particularly virulent strain and can cause death of *H. hampei* in 5 days (Cochereau et al. 1994). Moist, warm conditions favour the incidence of this pathogen, and heavy rain is thought to enhance the rate of infection. If spraying with fungal preparations is avoided on the day of release of parasitoids, adverse effects on the latter are not observed (Reyes et al. 1995). Friederichs (1922) recommended the encouragement of heavy shade to increase the incidence of fungal pathogens, but this runs counter to the fact that intensity of shade must often be reduced to encourage hymenopterous parasitoids which, however, may still prove to be of minor significance in population regulation. Certainly, Klein Koch (1989a) considered *Beauveria* to be the most important natural enemy of *H. hampei* in Ecuador. In Colombia, preparations of selected strains of *Beauveria* in oil have produced 20 to 95% adult mortality, slightly higher than the 20 to 90% produced by selected strains of *Metarhizium* (P. Cochereau, pers. comm. 1995). Varela and Morales (1996) have characterised a number of *Beauveria* isolates and their virulence against *H. hampei*.

Pascalet (1939) advocated the spraying of suspensions of spores, before sunrise, but no results are available. As with so many parasitic fungi, its application would be limited by intolerance of dry conditions. Another fungus that attacks *H. hampei*, *Paecilomyces javanicus*, is Afro-Asian in distribution and wide spectrum in its host range (Samson 1974), attacking also Lepidoptera. Its use against *H. hampei* appears not to have been attempted.

There appears to be only one record of nematodes attacking *H. hampei* in the field (Varaprasad et al. 1994), but in addition, Allard and Moore (1989) showed that a *Heterorhabditis* sp. could cause high mortality of both adult and larval *H. hampei* under laboratory conditions and that infective juveniles were produced from adults and larger larvae. Spraying of nematodes on fallen berries might remove the need to collect them (which involves much labor), leaving them to provide mulch. Dispersal of infected adults may also spread the nematodes into the pest population. Further work with nematodes is clearly desirable.

Table 4.10.1 Natural enemies of *Hypothenemus hampei*

Species and type	Country	Reference	Comment
HEMIPTERA			
PYRRHOCORIDAE (Predator) *Dindymus rubiginosus*	Java	Wurth 1922	Not specific
HYMENOPTERA			
BETHYLIDAE (ectoparasites of immature stages)			
Cephalonomia stephanoderis	Ivory Coast	Betrem 1961; Ticheler 1961; Cochereau & Potiaroa 1994;	A promising parasite
	Togo	Klein Koch et al. 1988	
Goniozus sp.	Ivory Coast	Cochereau & Potiaroa 1994	
Prorops nasuta	Cameroon	Klein Koch et al. 1988	
	Congo	Klein Koch et al. 1988	
	Ivory Coast	Klein Koch et al. 1988	
	Kenya	Klein Koch et al. 1988	
	Tanzania	Rangi et al. 1988	
	Togo	Klein Koch et al. 1988	
	Uganda	Klein Koch et al. 1988; Klein Koch et al. 1988; Waterston 1923	
Scleroderma cadaverica	Uganda	Benoit 1957	Causes severe dermatitis in man
CERAPHRONIDAE			
Aphanogmus (= *Calliceras*) dictynna	Uganda	Waterston 1923	Possibly hyperparasitic
EULOPHIDAE			
Phymastichus coffea (attacks adult beetles)	Ivory Coast	Cochereau & Potiaroa 1994	
	Kenya	La Salle 1990	
	Togo	Klein Koch et al. 1988	

Table 4.10.1 (cont'd) Natural enemies of *Hypothenemus hampei*

Species and type	Country	Reference	Comment
HYMENOPTERA			
BRACONIDAE			
(ectoparasitoid and predator)	Uganda	Schmiedeknecht 1924	Kills larvae with sting
Heterospilus coffeicola	Tanzania	CIBC 1988b	Attacks larvae of other parasites of
	Cameroon	Klein Koch et al. 1988	*H. hampei* — also may be
	Congo	Klein Koch et al. 1988	cannibalistic
FORMICIDAE			
(predator)			
Crematogaster curvispinosa	Brazil	Pinto da Fonseca & Araujo 1939	Can cause high mortality of immature stages in coffee berries
ACARI			
Pyemotid mite	New Caledonia	P. Cochereau pers. comm.	
NEMATODA			
Heterorhabditis sp.		Moore & Prior 1988	
Panagrolaimus sp.	India	Varaprasad et al. 1994	
FUNGI			
HYPHOMYCETES			
Beauveria bassiana	Java	Friederichs & Bally 1922	Cosmopolitan, in a variety of strains
(= *Botrytis stephanoderis*)	Cameroon	Pascalet 1939	
Metarhizium anisopliae		Moore & Prior 1988	
Nomuraea rileyi		Moore & Prior 1988	Usually recorded from Lepidoptera
Paecilomyces (= *Spicaria*) *javanicus*	Java	Friederichs and Bally 1922; Samson 1974	Indonesia, Asia, Africa
P. tenuipes		Moore & Prior 1988	

Attempts at biological control

Published information is summarised in Table 4.10.2. but there were probably a number of transfers of parasites within Africa and perhaps South America that have gone unrecorded. In the past decade the International Institute for Biological Control had adopted the policy of breeding African parasitoids in England on *H. hampei* in coffee beans from the country of destination. This is because of the possibility that the wasps might carry spores of fungal diseases of coffee, especially new strains of coffee leaf rust (*Hemileia vastatrix*) and coffee berry disease (*Colletotrichium coffeanum*) (Moore and Prior 1988; Rangi et al. 1988; Nemeye et al. 1990; Murphy and Rangi 1991). The danger of fungal transmission could also be reduced by breeding *H. hampei* on an artificial diet (Brun et al. 1993; Perez et al. 1995; Villacorta 1985).

Africa

CAMEROON

Pascalet (1939) recommended the introduction of *Heterospilus coffeicola*, *Prorops nasuta* and *Beauveria bassiana* to any plantations lacking them. There is no record that this was implemented anywhere, nor whether any or all of the organisms were not already generally present.

CONGO

Sladden (1934) and Leroy (1936) suggested that, by breeding and liberating them, it would be possible to increase the efficiency of *P. nasuta* and *H. coffeicola*, which he knew to be already present in the Congo and he made a similar suggestion for fungus diseases. However, there is no indication of the extent to which this was done.

KENYA

Prorops nasuta was sent from Uganda to Kenya in 1930 (Greathead 1971), but according to Evans (1965) that wasp and *H. coffeicola* were probably native there. Abasa (1975) considered that parasites were of doubtful value in controlling *H. hampei* in Kenya.

UGANDA

Prorops nasuta and *Heterospilus coffeicola* are both native to Uganda. Hargreaves (1935) considered that some areas lacked these parasites, and so he introduced cultures from Kampala County, north of Lake Victoria, to Bwamba County on the western border. He stated that this introduction resulted in a great reduction in the previously intense infestation of coffee berry borer but, in view of the natural occurrence of *P. nasuta* over a wide area to the west of the Ugandan border (Le Pelley 1968), it seems unlikely that the distribution was discontinuous and that it was lacking in Bwamba

County. Hargreaves' claims that the introduction brought about a great reduction in the impact of the coffee berry borer in Bwamba County must be treated with reserve, the more so since De Toledo Piza and Pinto da Fonseca (1935) state that neither *P. nasuta* nor *H. coffeicola* appeared to control the borer in nearby Kampala. More recently, *P. nasuta* was reported to achieve 20% parasitisation in western Kenya in the dry season (Barrera et al. 1990b).

Asia

SRI LANKA

Stock of *P. nasuta* and *H. coffeicola* from Uganda were liberated in Sri Lanka in 1938, but neither species became established (Hutson 1939).

INDONESIA

The introduction of *Prorops nasuta* to Java from Uganda in 1923 was the earliest attempt to bring about the biological control of *H. hampei* which had first been reported in Java in 1909 (Kalshoven 1981). *P. nasuta* was found to be easily propagated (Leefmans 1924a), was distributed widely in considerable numbers (Begemann 1926) and became established (Le Pelley 1968). However, it apparently could not maintain itself and was still being bred for distribution in 1928 (Ultée 1928) and in 1932 (Betrem 1932; Schweizer 1932; Ultée 1932).

Leefmans (1924a) drew attention to the fact that the *P. nasuta* did not thrive in shade, and that it flourished best in black berries which tend to be most abundant after harvest, when the parasite is least needed. The former problem was solved by appropriate pruning but, despite improvements in management to favour it and the long period spent in breeding and disseminating it, the parasite seems not to have become established in Java (Clausen 1978; Kalshoven 1981).

Cultures of *Heterospilus coffeicola* were taken to Java from Uganda along with those of *P. nasuta* in 1923, but the wasp appears not to have been released. Leefmans (1924a) seems to have concluded that it was likely to be incompatible with *P. nasuta*.

Table 4.10.2 Introductions for the biological control of *Hypothenemus hampei*

Country and species liberated	Year	From	Result	Reference
BRAZIL				
Cephalonomia stephanoderis	?	?	+	Benassi & Berti-Filho 1989
Prorops nasuta	1929	Uganda	+	Hempel 1933; Yokoyama et al. 1978
COLOMBIA				
Cephalonomia stephanoderis	1988	Kenya via U.K.	+	C. Klein Koch pers. comm. 1995; Sponagel 1993
Prorops nasuta	1995		+	Bustillo et al. 1995; Portilla & Bustillo 1995
ECUADOR				
Cephalonomia stephanoderis	1988	Togo via U.K.	+	CIBC 1988b; Klein Koch 1989a,b,c; Klein Koch et al. 1988; Delgado et al. 1990; Sponagel 1993
Prorops nasuta	1987–1990 1988	Kenya via U.K. West Africa	– –	CIBC 1988a; Klein Koch et al. 1988; Rangi et al. 1988; Murphy & Rangi 1991; Sponagel 1993
EL SALVADOR				
Cephalonomia stephanoderis	1988	Kenya via U.K.	+	Sponagel 1993; C. Klein Koch pers. comm. 1995
GUATEMALA				
Cephalonomia stephanoderis	1988 1993-1995	Kenya via U.K.	?	Sponagel 1993 Garcia & Barrios 1996
HONDURAS				
Cephalonomia stephanoderis	1988	Kenya via U.K.	?	Sponagel 1993

Table 4.10.2 (cont'd) Introductions for the biological control of *Hypothenemus hampei*

Country and species liberated	Year	From	Result	Reference
INDONESIA				
Cephalonomia stephanoderis	1988		?	Sponagel 1993
Heterospilus coffeicola	1923	Uganda	not liberated	Kalshoven 1981
	1931	Uganda	?	Le Pelley 1968
Prorops nasuta	1923–1925	Uganda	–	Begemann 1926 Kalshoven 1981
KENYA				
Prorops nasuta	1930	Uganda	already present	Evans 1965
MEXICO				
Cephalonomia stephanoderis	1988–1989	Togo via U.K.	+	Barrera et al. 1990 a, b; CIBC 1988b
Prorops nasuta	1988–1989	Kenya and Togo via U.K.	?	Barrera et al. 1990a, b; Murphy & Rangi 1991
NEW CALEDONIA				
Cephalonomia stephanoderis	1993	Ivory Coast	+	Cochereau & Potiaroa 1994
UGANDA (BWAMBA COUNTY)				
Prorops nasuta	1932	Uganda (Kampala county)	+ ?already present	Hargreaves 1935
PERU				
Prorops nasuta	1962			Clausen 1978
	1964?	Brazil	–	De Ingunza 1964
SRI LANKA				
Heterospilus coffeicola	1938	Uganda	–	Hutson 1939
Prorops nasuta	1938	Uganda	–	Hutson 1939

Pacific

NEW CALEDONIA

Infestation of coffee berries with *H. hampei* ranges from 0% to 100%, with an overall average of 33%. *C. stephanoderis* from West Africa was released in 1993 and recovered almost a year later. However, wherever the aggressive, little red fire ant (*Wasmannia auropunctata*, introduced around 1970) is present this parasitoid is unable to survive. When the fire ant is eliminated from a plantation by banding the trees with insecticide the wasp is established. Ant control is, thus, a prerequisite for biological control (Cochereau and Potiara 1994; P. Cochereau pers. comm. 1995). *Phymastichus coffea* is currently under consideration for liberation (P. Cochereau pers. comm.). Cochereau et al. (1994) have examined in some detail the effectiveness against *H. hampei* of a virulent New Caledonian strain of *Beauveria bassiana*, which shows considerable promise in the field.

Central America

GUATEMALA

Cephalonomia stephanoderis was mass produced and released during 1993 to 1995. Infestation by *H. hampei* was reduced 75%, to 2.7 to 5.3% in 1993 and to 0.4 to 0.9% in 1994, but an increase was observed in 1995 (1.6 to 2.4%, compared with the control of 3.8% infestation), resulting in 48% control (Garcia and Barrios 1996). The cost of mass liberations of *C. stephanoderis* was comparable with that of chemical control (Decazy et al. 1995).

MEXICO

Cephalonomia stephanoderis from Togo and *Prorops nasuta* from both Togo and Kenya were raised in U.K. in coffee beans from Mexico before being sent there for mass production and liberation during 1988 and 1989. *C. stephanoderis* has become established, but the situation with *P. nasuta* is unclear (Barrera et al. 1990a, b). The impact of these parasitoids remains to be reported.

South America

BRAZIL

Prorops nasuta was imported into Brazil from Uganda in 1929, and by 1933 it was established in several coffee plantations (Hempel 1933, 1934). As in Java, breeding and distribution continued and in 1937 (Anon. 1937) it was stated to be of considerable value in controlling the coffee berry borer in São Paulo, but only if its numbers were boosted by rearing between coffee production seasons. Puzzi (1939) studied the reproduction of the parasite in relation to that of its host in Brazil and concluded that, in theory, it was more prolific, but that the efficiency of the parasite was limited by the tendency of the female to remain in one berry. De Toledo (1942) examined rates of parasitisation, but his figures do not suggest that the wasp could have been having any significant impact. De Toledo et al. (1947) were only mildly enthusiastic about the value of the wasp, mentioning a continuing need for repeated liberations and the requirement for boosting the effect of the parasite by cultural practices. Le Pelley (1968) stated that, at that time, Brazilian entomologists appeared satisfied that *P. nasuta* was of value in their country, but he could find no conclusive evidence that the amount of routine work required for the control of *H. hampei* had decreased. Yokayama et al. (1978), considered that the climate of the São Paulo district in Brazil was unfavourable for this wasp, in which the growers lost interest when BHC was found to give satisfactory control. Nevertheless, they reported that it had recently been recovered in coffee plantations in São Paulo, having survived pesticide usage, severe droughts and winter frosts. The fact that *P. nasuta* has been transferred more recently to areas in Brazil where it is not established indicates that the wasp is considered to be of some value (Ferreira and Batistela Sobrinho 1987).

Although there is no record of its release, a species of *Cephalonomia*, presumably *C. stephanoderis* was recovered in the field in Brazil between 1986 and 1988 (Benassi and Berti-Filho 1989).

A survey of natural enemies of *H. hampei* in northern Espirito Santo from 1986 to 1994 revealed 3 parasitoids (*Prorops nasuta*, *Cephalonomia* sp., and a species of Proctotrupoidea), an ant predator (*Crematogaster curvispinosa*) and a fungus (*Beauveria bassiana*) (Benassi 1995).

COLOMBIA

The rate of population increase of *H. hampei* in the field has been studied by Gaviria et al. (1995). A major program of integrated management commenced in 1992, involving local strains of the fungi *Beauveria bassiana* and *Metarhizium anisopliae* and parasitoids, in particular *Cephalonomia stephanoderis* and *Prorops nasuta* (CABI: IIBC 1993; C. Klein Koch pers. comm. 1994; Bustillo et al. 1995). Methods for mass production of *C. stephanoderis* and *Prorops nasuta* are provided by Portilla and Bustillo (1995). Sixty million parasitoids were released and 100 tons of *B. bassiana* and *M. anisopliae* were applied (Bustillo et al. 1995).

ECUADOR

Klein Koch (1986) proposed the introduction of 3 parasitoids from Africa, *Prorops nasuta*, *Heterospilus coffeicola* and *Cephalonomia stephanoderis*. *C. stephanoderis* was first introduced from Togo in 1988 and *P. nasuta* from Tanzania and Kenya in 1987–88 and Togo in 1988 (Klein Koch 1989c).

Liberations continued in subsequent years with some 920000 of the former species and 30,000 of the latter being released in 1992. Both species are now well established and having a significant effect. In field experiments with caged coffee trees 86% of berries on the bush and 87% on the ground contained *C. stephanoderis* and up to 52% and 31% parasitisation respectively was recorded from tree and ground berries in the open (Klein Koch 1989b,c, 1990). However the results are poor in the Amazon region of the country where the rainfall is very high. Elsewhere, as part of an integrated approach, infestation levels on *Coffea arabica* are as low as 0.4 to 1.4%. Recently introduced *catimor* varieties are resistant to coffee rust, so sprays are no longer required (Klein Koch pers. comm. 1994). In addition, the fungus *Beauveria bassiana* and the ant *Azteca* sp. cause considerable mortality of *H. hampei* when humid weather conditions prevail (Klein Koch et al. 1987).

PERU

According to De Ingunza (1964) *Prorops nasuta* was introduced from Brazil to Peru in 1962, but failed to become established.

Major parasite species

Cephalonomia stephanoderis Hym.: Bethylidae

Cephalonomia stephanoderis is a small black bethylid wasp which is native to West Africa (Ivory Coast, Togo). The females, which are 1.6 to 2.0 mm in length, enter bored coffee berries and deposit eggs on the ventral surface of final stage larvae and prepupae of *H. hampei*. Its larvae feed as ectoparasites, exhausting the tissues of the host in 4 to 6 days, then spinning a silken cocoon in which to pupate. The pupal stage lasts about 15 days. Fertilisation takes place in the berry where the wasps emerge, and seemingly, the males, although fully winged, remain there after the females have left. Females must feed for two days at 27°C or 6 to 11 days at 24°C before they can mature eggs. Adult females feed by preference on *H. hampei* eggs and young larvae but also on prepupae and they chew holes in the intersegmental membrane of adult beetles, between the prothoracic and mesothoracic tergites, and feed on the haemolymph. Females cannot produce eggs on a diet of borer eggs or adults alone, but need to feed first on the larvae and/or prepupae of the borer. They can lay up to 70 eggs (Barrera et al. 1989, 1993; Abraham et al. 1990; Wegbe 1990; Infante et al. 1994a) and can distinguish between parasitised and unparasitised hosts (Barrera et al. 1994). In the Ivory Coast, Koch (1973) found that adult *C. stephanoderis* each required two eggs, two larvae or two adults per day for survival. At the end of the coffee season *H. hampei* populations were reduced by parasitisation by 20%

to 30%, but by not more than 5% between seasons. Ticheler (1961) recorded up to 50% parasitisation by this, the most important parasitoid in the Ivory Coast. In West Africa *C. stephanoderis* is commoner than *P. nasuta* (Abraham et al. 1990). A major mass production and release program commenced in Colombia in 1993, with a production of 10 million wasps per month. When 400 000 wasps were released in a 2 million ha area of coffee trees 85% parasitisation was attained when there was 80% infestation of coffee berries and 20% parasitisation when there was 5% infestation. The target for the releases was 12.5 wasps per berry and 300 berries containing wasps for each 15 trees, giving 20 000 to 30 000 wasps per ha (P. Cochereau pers. comm. 1995). Life tables were developed for *C. stephanoderis* in Mexico (Infante and Luis 1993; Infante et al. 1994b).

Studies of mass releases of *C. stephanoderis* suggest that they can control low density populations of *H. hampei* in commercial coffee plantations, adult predation by the wasp probably being the most important mortality factor. However, mass production costs are too high for releases to be economically viable and cheap artificial diets for mass rearing are being investigated, with successful rearing already achieved for four generations (CABI:IIBC 1996).

Heterospilus coffeicola Hym.: Braconidae

Heterospilus coffeicola is a braconid wasp about 2.5 mm long. It does not enter the borehole of the beetle, but travels from berry to berry inserting its ovipositor into the boreholes in the course of seeking *Hypothenemus* larvae. Only one small egg is laid in each berry, and the larva that emerges after about six days feeds on beetle eggs and larvae over a period of 18 to 20 days, consuming 10 to 15 eggs and larvae per day. In this regard it is more of a predator than a parasite. According to De Toledo Piza and Pinto da Fonseca (1935) the larva kills the adult *H. hampei* before pupating inside a white silken cocoon. The wasp emerges after a comparatively brief pupal period (Hargreaves 1926; De Toledo Piza and Pinto da Fonseca 1935, Le Pelley 1968). In Uganda it is attacked by a chalcidid of the genus *Closterocerus* (Schmiedeknecht 1924).

Hargreaves (1926, 1935) stated that *Heterospilus coffeicola* contributed substantially to the control of *H. hampei* in Uganda. The Brazilian entomologists De Toledo Piza and Pinto da Fonseca (1935) studied the wasp in Uganda with a view to assessing its potential value as a biological control agent in Brazil. They concluded that *H. coffeicola* can thrive only in areas with a continuous production of coffee berries throughout the year, and as such conditions prevail nowhere in Brazil they recommended against its importation. One possible disadvantage of this wasp is that its larvae feed on the larvae of other wasps as well as those of *H. hampei*, and it may even be cannibalistic (Hargreaves 1924). If these statements are verified then there may be reservations about the employment of *H. coffeicola* in biological control. A further difficulty associated with this species as a biological control agent is that a number of workers have been unable to breed it in the laboratory, a problem also experienced by CIBC (1987) during its current program, although Rangi et al. (1988) have reported limited success. The free-living existence of the adults may involve special nutritional or mating requirements that have not yet been met experimentally.

Phymastichus coffea Hym.: Eulophidae

This parasitoid was first recorded in Togo as recently as 1989 (Borbon-Martinez 1989), causing up to 30% parasitisation, but is now known also from Ivory Coast and Kenya. It is an endoparasite of the adult female *H. hampei*, which is usually attacked as she is commencing to tunnel in to a coffee berry. *P. coffea* also enters the berry to parasitise male *H. hampei*. Oviposition occurs in both the thorax and the abdomen of the host, the former producing a male and the latter a female. Although several eggs may be laid in each host, only two wasps are produced. Males range in length from 0.45 to 0.55 mm and females from 0.8 to 1.0 mm. Females do not require to be fertilised before they commence oviposition shortly after emergence. At 27°C, larval development takes about 21 days, the pupal stage about 8 days and adult longevity appears to be a few days only. In the field 20 females were produced for each male and it was estimated that between 4 and 7 hosts could be parasitised in a 4-hour period.

P. coffea was the most important parasitoid of *H. hampei* in the majority of coffee holdings on the Togolese Plateau at about 800m above sea level and is fairly common around Man (West Ivory Coast) near the Liberian border (La Salle 1990; Feldhege 1992; P. Cochereau pers. comm. 1994; Infante et al. 1994a,).

Mass production methods have been developed in Colombia for *P. coffea* and a decision to release is expected shortly (CABI:IIBC 1996).

Prorops nasuta Hym.: Bethylidae

Prorops nasuta is native to Uganda, Kenya, Tanzania and Cameroon, Ivory Coast and Togo. It is a dark brown bethylid wasp about 2.3mm in length, the name *nasuta* referring to the characteristic bilobed 'nose' protruding forwards above the antennal bases. This wasp parasitises and preys upon several species of *Hypothenemus* (Clausen 1978). Males that emerge first from pupae always stay on the remaining cocoons within the coffee berry and mate with the females as they emerge. Because *P. nasuta* populations are, thus, highly inbred it is probable that there are different strains of

P. nasuta in West Africa and East Africa, (Abraham et al. 1990; Griffiths and Godfray 1988; Murphy and Rangi 1991) and testing these may be highly relevant to biological control. On coffee the fertilised female enters an infested berry via the borehole of the adult *H. hampei*, choosing berries on the trees rather than those on the ground. If the parent borer beetle is still present she may kill it and use the cadaver to plug the entrance hole, over which she stands guard. According to CIBC (1987) the female wasp does not feed upon borer beetles she may kill, but other authors state that she will do so if no other life history stages are available, but that she cannot mature eggs on a diet of adults alone. Several larvae and pupae may be injured with the ovipositor before any oviposition occurs, and these victims succumb in a few days. *P. nasuta* feeds by preference on the eggs and young larvae of *H. hampei* and oviposit on the late third stage larvae and pupae. The hosts chosen for oviposition are stung, sometimes several times, and thus paralysed before one, or sometimes two, eggs are laid upon them. Eggs are placed ventrally on larvae and on the abdominal dorsum of pupae. The eggs (0.55 x 0.18mm) are large for a wasp of this size. They hatch in an average of about three days and the larval stages last three to eight days. The ectoparasitic larva may consume more than one host. There is a prepupal (non-feeding) period of about three days, passed inside a silken cocoon spun by the fully fed larva. It is common to find 20 cocoons in a coffee bean, and up to 62 have been recorded. The pupal stage lasts on an average about 21 days, varying from 9 to 27 days according to temperature.

The life cycle from egg to adult lasts 17 to 33 days (average 29) at 25°C and may be as long as 66 days at 18°C. There are considerable discrepancies between figures given by various authors for the duration of the life history stages, but there is general agreement that the female is quite long-lived — up to 135 days being cited in Brazil, given an abundant supply of larvae and prepupae as food. By contrast it appears that the males do not feed and they do not survive longer than 13 days. Females outnumber the males, a figure of three to one being recorded. Statements as to duration of the preoviposition period give rather diverse figures. Usually a few days are indicated but one record is of 17 days. Parthenogenesis may occur, when only male progeny are produced. Females may lay up to 66 eggs at a rate of one or two a day, utilising several berries in the process.

In feeding, females consume several eggs and unparasitised larvae per day and they will also eat pupae. Normally all stages of the beetle in a berry are killed either by parasitisation, predation or merely by stabbing before the female leaves (Leefmans 1924a; Begemann 1926; Hempel 1933; De Toledo Piza and da Fonseca 1935; Hargreaves 1935; Hutson 1936; Puzzi 1939; De Toledo 1942; Le Pelley 1968; Abraham et al. 1990;). The low abundance of

P. nasuta in Western Kenya suggests that it may not be suited to high altitudes (Murphy and Rangi 1991). In one locality in São Paulo (Brazil) the percentage of infested berries that contained parasitoids rose to a maximum of 2.4 in autumn (De Toledo 1942).

Scleroderma cadaverica Hym.: Bethylidae

Scleroderma cadaverica is listed by Herting and Simmonds (1973) as a natural enemy of *H. hampei*, but only some of the specimens before Benoit (1957) when he prepared the taxonomic description had been reared from that species, others being stated to come from small beetles boring in cane furniture. The North American species of *Scleroderma* are stated by Krombein et al. (1979) to be parasitic on the larvae of small wood-boring beetles, the female wasps frequently stinging people inhabiting infested houses. The African specimens of *S. cadaverica* were submitted to European specialists for identification and description because stinging by females (which may be either winged or apterous) had caused severe dermatitis to African and European people. No responsible person would consider using this insect in biological control projects.

Comments

Hypothenemus hampei has established itself in most of the coffee growing areas of the world, but there are still uninfested countries, such as Australia, Hawaii, Papua New Guinea, Vanuatu and the Solomon Islands. Quarantine is of critical importance to these countries and it is important to ensure that coffee imported into clean areas has been completely disinfested. Thorough drying of the seed coffee is an indispensable supplement to disinfestation techniques.

Although great advances have been made in recent years in the chemical control of *H. hampei*, it would be a great advantage to have the support of additional measures. Rhodes and Mansingh (1981) found chemical control inadequate on its own in Jamaica and advocated its integration with cultural practices and Bardner (1978) emphasised the need to harmonise cultural, biological and chemical control of coffee pests. Hernandez Paz and Penagos Dardon (1974) found, in Guatemala, that low-volume sprays of endosulfan could completely destroy *H. hampei* in berries on the bushes and, according to Mansingh and Rhodes (1983), this chemical is in extensive use in Central and South America. However, a very high level of resistance to endosulfan in *H. hampei* is reported in New Caledonia (Brun et al. 1989, 1990), raising concern that this valuable insecticide may not remain an effective material for long.

Plantation sanitation is an old-established tradition in pest control, and the coffee berry borer has long been attacked from this angle. The life cycle of the borer, indeed, lends itself to this approach, as it is narrowly specific to the coffee berries. In Java, Roepke (1912) and Leefmans (1924b) recommended the total destruction of infested or susceptible berries over a period long enough to break the life cycle of the coffee berry borer. A period of three months was aimed at, although some records of the longevity of beetles exceed this. Measures taken involve the collection of all fallen berries and the picking of any that may have escaped the harvest, plus the continuous removal of all young berries on which adult female beetles might feed. Friederichs (1922) and Rutgers (1922) reported successful application of the method in Java. The latter reported that, on estates which had applied the measures, the percentage of infested berries fell from 40% to 90% to between 0.5% and 3.0%. In New Caledonia application of the method reduced infestation from 80% to 10% (Cohic 1958). In Malaysia, Corbett (1933) recommended picking at weekly intervals (or the shortest period practicable, according to size of holding) of all bored green, ripe and blackened berries on the bush and from the ground. A host-free period of six months was recommended for the eradication of the beetle from isolated plantations. In Mexico, Baker (1984) concluded that berries are not infested while lying on the ground surface. Nevertheless any infested berries allowed to lie where they fell ultimately generated large numbers of beetles.

Turning to biological control, it is generally possible to gain some idea of the likely effectiveness of natural enemies in a new country from their impact in their country of origin. In a new country the enemies may be more effective if freed from hyperparasites before transfer or less effective if they are poorly adapted to their new environment. Based on their evaluation of the population dynamics of *H. hampei* and its parasitoids, Moore and Prior (1988) and Murphy and Moore (1990) were optimistic about the value of biological control as a key component of successful integrated management of *H. hampei*. Although this indeed seems probable, the reports from Africa are far from uniform and the coffee berry borer is a problem in some areas. This may be due to whether arabica or robusta coffee is involved and to the widely different conditions under which coffee is grown and harvested since, for example, parasitoids may be less effective when coffee is shaded (Hargreaves 1935).

Hargreaves (1926, 1935) considered that both *Prorops nasuta* and *Heterospilus coffeicola* were important in regulating populations of *H. hampei* in commercial coffee at about 1200m in Uganda and Pascalet (1939) arrived at a similar view concerning these parasitoids in Cameroon. On the other hand, Abasa (1975) in Kenya, De Toledo Piza and Fonseca

(1935) and Ingram (quoted by Le Pelley 1968, p 125) in Uganda and Sladden (1934) and Schmitz and Crisinel (1957) in Zaire concluded that parasitoids had little influence on the number of bored berries. Murphy and Moore (1990) considered that *P. nasuta* did not have a major impact in Western Kenya where *H. coffeicola* was not encountered. There, coffee berries infested with *H. hampei*, ranged in being attacked by *P. nasuta* from 0% in the wet season to 25% in the dry season and *P. nasuta* populations did not build up until after the annual coffee harvest when populations of *H. hampei* had already crashed from their annual peak.

Although *P. nasuta* is present in Ivory Coast (Diro, Man) it is usually rare and *H. coffeicola* apparently absent. However, *Cephalonomia stephanoderis* was common and up to 50% of colonies of *H. hampei* in black berries were parasitised, resulting in important population reduction (Ticheler 1961), a conclusion contested by Koch (1973) on unsubstantiated grounds. It is relevant that, in the presence of *C. stephanoderis*, but without any chemical treatment, Cochereau and Potiaroa (1994) reported that only 2% of the coffee beans (4% of the berries) were attacked in Ivory Coast by *H. hampei*. They contrast this with the situation in New Caledonia where it was common to find 50% of the berries bored, even in plantations treated with endosulfan.

Experience in biological control suggests that the negative assessments of the value of parasites in Africa may reflect the restraining influence of hyperparasites (such as *Aphanogmus* (= *Ceraphron*) *dictynna*), predators, competitors and diseases, but it seems that no such impediments were taken to Brazil with the original stocks of *Prorops nasuta*. Nevertheless, Le Pelley (1968) stated that there was no evidence that, 35 years after the introduction, Brazilian coffee growers had to invest less effort in other control measures and Yokayama et al. (1978), 45 years after its introduction, gave a depressing picture of its impact. Greater success may attend the more recent employment of *Cephalonomia stephanoderis*.

In spite of the conflicting reports, there are, on balance, good reasons for maintaining optimism that natural enemies can play an important role in reducing the losses caused by *H. hampei*. There are the still to be evaluated prospects that *C. stephanoderis* will prove useful and there are various strains (and intraspecific crosses) of *P. nasuta*, in addition to *Phymasticus coffea*, *Heterospilus coffeicola* and *Goniozus* to consider. It is quite possible also that further work, especially in countries such as Ethiopia, which have not been studied, will reveal additional parasitoid species. It is possible that nematodes may prove effective in controlling infestations in fallen berries and likely that applications of a virulent strain of *Beauveria bassiana* may prove to be a valuable alternative to pesticides. It is fortunate for Southeast

Asian countries that active work on both parasitoids and *B. bassiana* is in progress in a number of South American countries and in New Caledonia, from which valuable new information will emerge. However, this is not a justification to delay action if *H. hampei* is high enough on the priority list, since it is likely that parasitoid cultures and relevant expertise will be more readily and economically available now than they will be some years hence.